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HARPOON PYROTECHNIC SHOCK STUDY

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FOREWORD

This is a final report on the analysis of the Harpoon missile shock response to the various pyrotechnic events that will occur during a mission. The work, authorized by AIRTASK A05P-204/2162/6000/00000 issued by the Naval Air Systems Command, was performed from July 1973 to July 1979.

In the interest of economy and timeliness in presenting the information, the report is being published as originally submitted except for minor (typographical) changes to the text, formatting to NWC technical publication style, and preparation of the figures for reproduction.

This report has been reviewed for technical accuracy by William J. Werback.

Approved by
D. J. RUSSELL, *Head*
Engineering Department
15 August 1979

Under authority of
W. B. HAFF
Capt., U. S. Navy
Commander

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(U) *Harpoon Pyrotechnic Shock Study*, by Dan Powers, McDonnell Douglas Astronautics Co.; Charles E. Wright, Systems Consultants Inc.; and William N. Jones, NWC. China Lake, Calif., Naval Weapons Center, September 1979. 34 pp. (NWC TP 6133, publication UNCLASSIFIED.)

(U) A study was conducted to compare predicted Harpoon missile pyrotechnic shock response with Harpoon missile design criteria.

(U) This report discusses the pyrotechnic shock environment and component failures encountered in this type of environment. Correct shock test simulation techniques and "state-of-the-art" limitations are delineated. Actual testing techniques and test apparatus that can be used to achieve the proper test environment are discussed. Both actual test data and predicted shock levels are presented.

(U) Shock spectra environment predictions are made for several types of explosive activated devices. Test data were measured during Harpoon ejection tests and are presented as shock spectra.

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CONTENTS

1. INTRODUCTION

In its launch-to-target sequence, the Harpoon weapon involves the use of numerous ordnance activated components such as Marman clamps, pin pullers, engine start cartridges and igniters, quick activated batteries, ordnance activated valves, and ejection launchers. Most of these components are supplied as off-the-shelf items, although several are of special design. These types of components have characteristically generated high frequency shocks which have often proved detrimental to other equipment mounted in the general area of the ordnance device. Prediction of this type of shock must be based mainly on empirical results because, to date, no analytical method of prediction has proven successful.

The purpose of this study was to predict the shock environments generated from the devices listed above and to discuss the pyrotechnic shock phenomenon, failures encountered in this environment, and test techniques and apparatus required to ensure the proper simulation of the pyrotechnic shock environment. Shock environment prediction involved a literature search to find test data which could be used as a baseline, and an enveloping of the data to form a representative band. The predicted envelopes for the various devices are presented in Section 2.

Information for Section 3, covering test techniques and apparatus, was obtained from various technical papers and from past experience with pyrotechnic shock. The "state of the art" in pyrotechnic environmental simulation is changing rapidly; therefore, the material presented in Section 3 reflects current practice.

2. SHOCK SPECTRA PREDICTIONS

The types of devices delineated in Section 1, Introduction, have been used on, and tested for, numerous vehicle applications, including Harpoon. Tests to determine the shock levels they produce have been conducted by most aerospace companies. Unfortunately, because of the many types, sizes, and configurations, locating data which are applicable to a particular component becomes a difficult task. In many instances, information could not be obtained regarding the exact type of component to be considered, the type of structure it was mounted on, and details of the mounting configuration.

Fortunately, the shock levels generated by the devices under discussion fall into distinct classes. Thus, by grouping the components into particular classes and by gathering generally available information from other components which fall into these same classes, it was possible to predict the shock levels that will be generated by the devices.

The following general approach was used to predict shock environments.

Step 1. Group the devices into categories for which shock levels are similar and for which empirical data are available.

Step 2. Perform a literature search for test papers and reports published by the military and aerospace companies to obtain data applicable to the ordnance devices which fall into the categories defined in Step 1.

Step 3 Review the literature found in Step 2 and specifically choose data that were obtained 5 to 10 inches (127 to 254 mm) from the ordnance device. Selection of data taken this close to the source will minimize errors arising from structural response, distance and joint attenuation, etc.

Step 4 Envelope applicable data found in Step 3 for each of the categories defined in Step 1.

The exact prediction technique for each device is delineated in the following paragraphs. Predictions are presented in shock spectra format. The spectra shown are maximax spectra (envelopes of positive and negative spectra) and, except as otherwise noted, were generated using 5% damping (magnification factor Q=10). The spectral envelopes presented represent the predicted environment on the mounting structure 5 to 10 inches (127 to 254 mm) from the explosive device. Attenuation across the component mounting interface is the only loss considered.

2.1 BOOSTER CLAMP RING

This device was described as being typical of the Marman clamp design, using two 1/2-inch (12.7-mm) explosive bolts. Data compiled from References 1, 2, and 3 were used to form the curves shown in Figure 1. These curves, obtained from six independent tests, represent the maximum spectra generated from accelerometer outputs located 5 to 10 inches (127 to 254 mm) from the clamp. It is predicted that the spectra levels generated by the Harpoon booster clamp ring will lie within the envelope of the curves shown in Figure 1.

2.2 BATTERIES

The batteries were described as the quick activated type made by Eagle-Picher. Typically, an initiator ignites a gas generator and the pressurized gas ruptures a burst disc and pushes the electrolyte into the cells.

A battery of this type was used on the UpSTAGE Experiment.[4] An acceleration history obtained from its activation is shown in Reference 5. No shock spectra plots of the transient were available so spectra from transients of similar magnitude and frequencies were plotted.[6,7] The predicted levels are presented in Figure 2. It should be remembered that this prediction was based on a single acceleration history measurement and that the shock spectra presented must be viewed as being the approximate response that could be expected from transients of similar magnitudes, frequencies, and durations.

2.3 ENGINE START CARTRIDGES AND IGNITERS

Data obtained from both UpSTAGE [4] and Spartan [8] gas generator igniters were used for these predictions. Spartan data were obtained from transducers located 30 inches (762 mm) away from the shock source. These data were modified to account for distance and joint attenuation by procedures outlined in Reference 9. The data obtained from the UpSTAGE Experiment were from locations between 5 and 10 inches (127 to 254 mm) from the igniters, so were simply redrawn. It is predicted that engine start cartridges and igniters will produce shock levels whose spectra lie within the envelope of the curves presented in Figure 3.

2.4 INLET COVER

This device is considered to be similar to a pin puller. Information on pin pullers was obtained from Reference 2. The maximum spectra calculated from transducer outputs located from 5 to 10 inches (127 to 254 mm) from the pin pullers during four different tests are shown in Figure 4. Note that for two of these tests, spectra were calculated using 2% damping (magnification factor Q=25). It is predicted that the shock produced by releasing the inlet cover will generate a spectrum that lies within the envelope shown in Figure 4.

2.5 VALVES

The valves were described as the Conox type where a piston drives a ram, breaks a pressure disc, etc. Valves are activated by high pressure gas fed by supply lines. Sizes ranged from 1/4 to 1/2 inch (6.35 to 12.7 mm). Data from valves of this type were difficult to obtain. Preliminary test results from Viking 3/4-inch (19-mm) valves, as presented in Reference 9, were used for the prediction. Results showing the envelopes from 5 identical firings are presented in Figure 5.

It is of particular interest to note the large difference in levels due to the mounting orientation. Much higher levels were obtained when the piston axis was parallel to the mounting surface than when it was mounted perpendicular to it.

Due to the limited amount of information obtained and the rather surprising results of the data presented, it is recommended that this prediction be used with caution.

3. TEST SIMULATION TECHNIQUES

Methods of shock simulation have progressed through the years, but most are still far from adequate. Twenty to thirty years ago numerous apparatus were developed to simulate shocks occurring from bench handling, transportation (aircraft landings, forklift drops, impacts from hard-sprung trucks, parachute drops, etc.), and from various equipments which generate their own shock environments, such as large guns and catapult-launched aircraft.

Missiles and space vehicles, with delicate electronic packages, led to development of a new generation of shock generating devices and simulation techniques. Complex transients generated by these devices could not be duplicated by any of the existing classical pulse producing devices, such as drop testers. The solution was to utilize shock spectra conversion techniques whereby the shock spectrum of a complex transient could be enveloped by the shock spectrum of a classical pulse (half sine, terminal peak sawtooth, ramp, etc.). The electrodynamic shaker, through shock synthesis techniques, also came into widespread usage as a shock machine.

The rationale for using a test that duplicates a shock spectrum rather than the acceleration history of the input is stated as: "A component subjected to a shock whose shock spectrum is the same as the shock spectrum obtained from the actual environment has been subjected to the same loading." This statement is rarely true. The following paragraphs in this section will attempt to explain some of the problems encountered in specifying and accomplishing tests which simulate shocks generated by pyrotechnic devices.

3.1 PYROTECHNIC SHOCK

A pyrotechnic shock is generated when an explosive device is initiated. These devices, in addition to those mentioned earlier, include separation nuts and bolts, cable and tube cutters, squib operated switches, and vehicle or fairing separation systems employing flexible linear shaped charges, mild detonating fuzes, etc. The magnitude of the shock generated by each type of device varies greatly. However, there is one common characteristic of all of these. The shocks are caused by an almost instantaneous release of energy. The outputs from transducers located close to the devices indicate short duration transients of high amplitude and frequency.

Caution must be used in making blanket statements about the characteristics of pyrotechnic shock. Figures 6 and 8 show the acceleration response of two accelerometers located at opposite ends of a Spartan missile. The transients were generated by detonating 25 grains per foot flexible linear shaped charge, which accomplishes vehicle separation.[10] Almost instantaneous peak loading is indicated near the separation plane (Figure 6), while 175 inches (4.4 m) away the input spectrum is completely masked by the 1,000 Hz structural resonance (Figure 8). It would be difficult to recognize the curve shown in Figure 8 as resulting from a pyrotechnic event even though it is just as much a pyrotechnic transient as the curve shown in Figure 6. The test apparatus used to simulate the 53,000 *g*, 0.2 ms spike (Figure 6) would undoubtedly be different from the one used to simulate the 329 *g*, 100 ms decaying sine (Figure 8). The point being made is that the test apparatus should be selected for its ability to reproduce the input, and not solely on its shock spectra reproduction capabilities.

Some conclusions can be drawn by examining the shock spectra plots of these two inputs. For quite some time experimenters have stated that time history pulses are overtests for pyrotechnic shocks because all time history pulse shock spectra have an initial slope of +6 dB/octave and the spectra from pyrotechnic transients exhibit slopes greater than +9 dB/octave. Consequently, enveloping a pyrotechnic shock spectrum with a pulse shock spectrum results in an overtest at the lower frequencies.[11-13] It is easily seen that enveloping the spectrum presented in Figure 7 (15 dB/octave rise) or the one in Figure 9 (26 dB/octave rise) with a pulse spectrum having a 6 dB/octave rise will certainly result in an overtest. There are many pyrotechnically generated shock spectra, however, that can be fitted rather well with the spectra from time history pulses. Also, the number of zero crossings should be considered. Time history pulses do not cross zero whereas pyrotechnic pulses will cross zero several times. Figures 10, 12, and 14 are examples.

It is worthwhile to mention that the shock spectrum of the Dirac function also has a slope of +6 dB/octave. Shocks having this characteristic are ones of infinite magnitude and infinitesimal duration. Figure 6 is a plot of the output of an accelerometer located 5 inches (127 mm) from a shock source. Maximum response levels at the shock source would undoubtedly be of even greater magnitude and shorter duration, and shock spectra generated from them would approach an initial slope of +6 dB/octave. If the acceleration history at the source did, in fact, resemble the Dirac function, and if it were possible to generate pulses of these levels and durations, then a test using a pulse to simulate the actual pyrotechnic loading would be a good approach.

The transients shown in Figures 10, 12, and 14 are extremely oscillatory and do not in any way resemble a single pulse, even though shock spectra generated from them can be enveloped rather nicely with typical pulse spectra (see Figures 11, 13, and 15). Using classical pulses to simulate these transients has serious drawbacks; numerous investigators have arrived at the same conclusion.[14-16] The abstract from Mr. J. Garibaldi's paper presented at the 43rd Shock and Vibration Symposium sums it up rather well:[17]

> "It has long been suspected that the damage potential of shock pulses can vary with the pulse characteristic even though the pulses have the same shock response spectrum. A quantitative test investigation was made of the dynamic environment associated with shock response spectrum inputs created by different time domain transients. A test device was exposed to three different time transients: half sine, shock synthesized on vibration exciter, and pyrotechnic. The test revealed an 8 to 1 variation in the response of the test device."

It must be pointed out that even if the acceleration history from the actual environment could be exactly duplicated by the test apparatus, shaker, drop tester, etc., the response at the part in the pyrotechnic environment would still not be duplicated because of dissimilarities in the transmission path.

Pulse generating test apparatus or shakers usually consist of a table, carriage, head, etc., upon which a part to be tested is mounted. The input pulse is assumed to be uniform over the entire mounting surface and, consequently, the load is applied simultaneously to every attachment or contacting point on the unit under test. In the real pyrotechnic environment, the input is in the form of tension and compression waves traveling through the structure and into the part. Thus, all mounting points are not loaded simultaneously. Dissimilarities in impedances between the test apparatus and actual mounting structures are another source of error.

It is assumed that the reader is familiar with shock spectra analysis and the drawbacks associated with its use for describing responses for other than single degree of freedom systems. Consequently, problems arising from using a single degree of freedom model to describe a multi-degree of freedom system are not covered in this report.

3.2 FAILURES FROM SHOCK LOADING

One of the main reasons for conducting shock tests is to determine if equipment will successfully function during and/or after being exposed to an actual shock environment. In order to specify an adequate test, it is necessary to know the equipment and its various failure modes. If the test is an adequate simulation, it must reproduce the same failure that would occur in actual service. Typically, pyrotechnic shock environments cause failures in fragile components or those having high natural frequencies. Actual structural failures are uncommon in this type environment. If the equipment to be tested does not have components with high natural resonant frequencies, then a shock test performed on a shaker using synthesis methods will probably produce the same failure as the actual pyrotechnic environment. Mr. Noble [15] reports on Centaur electronics utilizing cantilever beams in micro-miniature circuits to take the place of an inductance. The lowest natural frequency of these little beams was 8,000 Hz. Utilizing a shaker which has severe roll-off above 3 kHz, would probably not produce the same failure as the actual environment.

As mentioned in Section 3.1, duplication of shock spectra does not necessarily mean that failure modes have been duplicated. Classical pulses or time history pulses have often been called velocity shocks because of their large velocity content. If the pyrotechnically generated transients shown in Figures 10, 12, and 14 are examined, it can be seen that they are extremely oscillatory and that the positive and negative peak accelerations are approximately of the same magnitude. This fact is readily apparent in that the positive and negative shock spectrum are almost identical (Figures 11, 3,and 15). Velocity, the integral of acceleration, is equal to the area under the acceleration history plot. The areas above and below the abscissa of pyrotechnic transients are usually approximately equal, and consequently, their velocity content is negligible. Since the classical pulses are all one-sided, they all have a large velocity content. If a part is to survive a pulse shock test, it must have the ability to absorb a large amount of energy.

Kuoppamki and Rouchon[14] reported repeated failures of three small mounting screws when a part was subjected to a 200-*g*, 1-ms half-sine pulse. Several static firings were made and no failures were noted. Eight shock tests were performed on a shaker using shock synthesis methods and no failures occurred even though the shock spectrum of the shaker response exceeded that of the half sine by at least 50%. Harpoon actuators failed half-sine tests even though the shock spectrum of the clamp ring bolt was significantly higher. Further insight into these failures may be obtained by reviewing some basic differences between static and dynamic loading.[18]

1) The velocity of crack propagation is generally much lower than the velocity of propagation of the shock pulse; consequently, any cracks that are formed do not have time to grow before the pulse has passed on and the stress has been removed.

2) Since shock pulses cause large stresses in any one small part of the specimen at any one time, fractures may form in one region quite independently from what may be occurring elsewhere.

3) The dynamic elastic behavior of materials differs considerably from the static elastic behavior.

Much work has been done with regard to point 3. Terminology for new material properties has been developed; i.e., transition velocity, critical impact velocity, critical delay time, etc. In general, it is found that the yield and ultimate stress of materials are increased with increase in strain rates. For example, the ultimate stress of a mild steel is 50,000 lbs/in^2 (344740 kPa) under static loading, and 80,000 lbs/in^2 (551584 kPa) when subjected to an impact that produces a strain rate of 1,000 inches/inch/second (25.4 m/m/second).[19] It is easy to see how tests which produce different strain rates could produce different failure results.

3.3 TEST APPARATUS

Three categories of test apparatus will be discussed in this section: drop testers, shakers controlled by shock synthesizers, and pyrotechnic shock fixtures. Unfortunately, each of the apparatus has serious drawbacks in pyrotechnic shock simulation. The technique is to choose the appropriate apparatus for the particular environment and test item configuration.

Pulse generating devices come in a wide range of styles and sizes. Some machines employ a pneumatically driven table which impacts upon resilient pads or lead pellets. Other machines are operated by a hydraulic-pneumatic system and pulse shape and duration are varied by changing metering pins. Free fall drop testers employ only the force of gravity. These machines have recently been classified as "drop testers."

The best thing that can be said for these devices for pyrotechnic shock simulation is that they are in widespread usage. Most dynamic laboratories and vendors have one or more versions at their disposal. As mentioned in the previous section, when used to simulate pyrotechnic shocks, they usually produce large undesirable overtests. Numerous electronic boxes have been literally destroyed by using these devices to simulate pyrotechnic shock. Justification for their use can sometimes be made if the unit to be tested is packaged extremely well, can absorb a large amount of energy, and has no low frequency resonances.

If the specification is given as a shock spectrum and a test engineer decides to use a pulse whose spectrum envelopes the requirement, preference should be given to the terminal peak sawtooth pulse. This is the only pulse whose positive and negative shock spectra are identical. Thus, it is possible to do a six axes test in only three drops. Use of other pulses requires that the part be turned upside down and dropped again in each axis.

Shakers controlled by shock synthesizers have become valuable shock testing tools. They can be used to simulate low level pyrotechnic shocks. Their inherent limitations are shaker resonances and maximum accelerations obtainable. Advantages lie in their ability to shape various spectra, minimum setup time, and input resemblance to pyrotechnic transients.

This last point requires further explanation. Numerous synthesizers are on the market. Each system generates "required" inputs in a different manner. One system utilizes superimposed sine waves while another digital system uses discrete packets of sine waves, each packet distinctly separated from the one preceding it. These apparatus, while generating the correct shock spectrum, reproduce a rapid sine test rather than the decaying transient typical of most pyrotechnic shocks. Other manufacturer's systems produce a decaying transient similar to the pyrotechnic transients except that its duration is longer and contains more cycles at the low frequencies. Again, care must be taken when selecting apparatus to ensure similarity with the actual input. Compromises must always be made, but choosing a synthesizer that produces an output in the form of a high frequency decaying transient with a duration less than 100 ms is a far better choice than using one that produces sine waves. The obvious solution to the above dilemma is to specify the duration of the shock transient that is to be used to synthesize a shock spectrum.

Pyrotechnic shock fixtures have been used for many years. All of these devices were built specifically to duplicate given pyrotechnic environments. Unfortunately, since there is such a large range of levels generated by various pyrotechnic shocks, there is no universal fixture. Existing approaches include "barrel testers,"[10] "flat plates,"[20] "flower pots,"[21] etc.

Distinct advantages of these devices are excellent simulation of actual pyrotechnic loading and their ability to achieve extremely high accelerations and high frequencies. Disadvantages lie in the relatively little control over spectral shaping, hazards in explosive handling, and the fact that there are not many existing facilities.

While this approach is undoubtedly the best simulation of pyrotechnic shock available today, because of the disadvantages mentioned above, it is seldom used unless there is no other way of performing the test, For instance, the spectrum requirement of the test described in Reference 10 went to 20,000 Hz and had a peak of 10,000 *g*--a pyrotechnic shock fixture was the only device that could produce this spectrum.

The one exception to the above is the aircraft launch ejection rack. The launcher is relatively inexpensive and safe to operate. The complex transient produced by the aircraft ejection launch cannot be duplicated by a single event and the transient would be extremely difficult to synthesize using an electrodynamic exciter.[22,23] A typical time history and shock response spectra are shown in Figures 16 and 17.

4. CONCLUSIONS AND RECOMMENDATIONS

The curves shown in Figures 1 through 5 reflect predicted levels that would be generated near the specified pyrotechnic device. To derive test criteria from these data, it will be necessary to

1) Identify the relationship between the pyrotechnic source and the component with respect to shock path distance, type of structure, and number of joints between the source and components.

2) Calculate distance and joint attenuation effects for each component and draw attenuated shock spectra curves for each pyrotechnic source to determine which source produces the most severe environment at the component.

3) Weight the shock spectrum curve that represents the worst environment for each of the components by the required qualification margin.

References 2 and 9 delineate various distance and joint attenuation characteristics for numerous structures.

Acceleration transients generated by the devices whose predicted spectra are shown in Figures 1 through 5 are all extremely oscillatory at distances over five inches (127 mm) from the source. On the basis of the information presented in Section 3, it is recommended that components required to operate in or survive these environments be tested on either pyrotechnic shock fixtures or shakers programmed by shock synthesizers.

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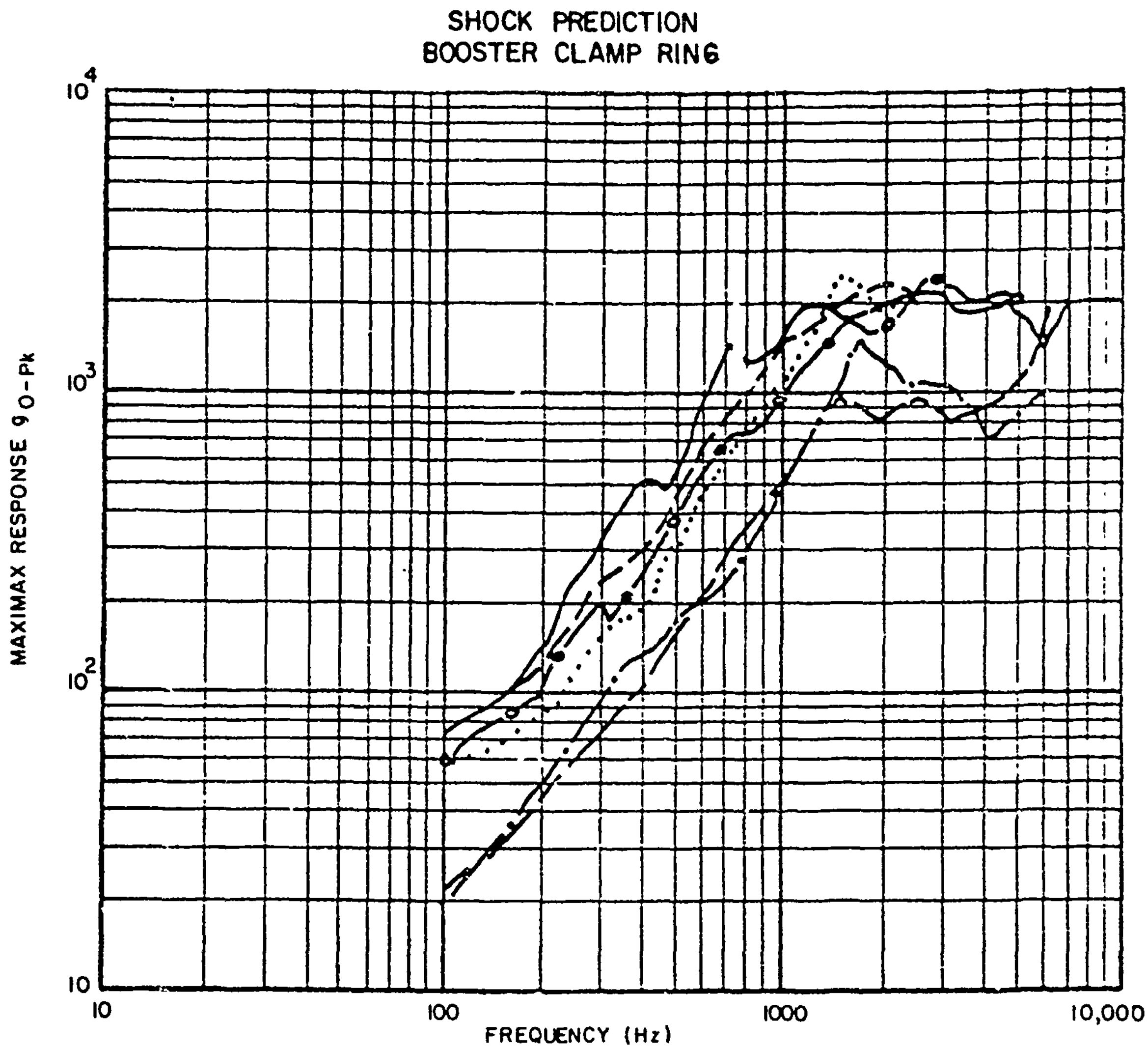

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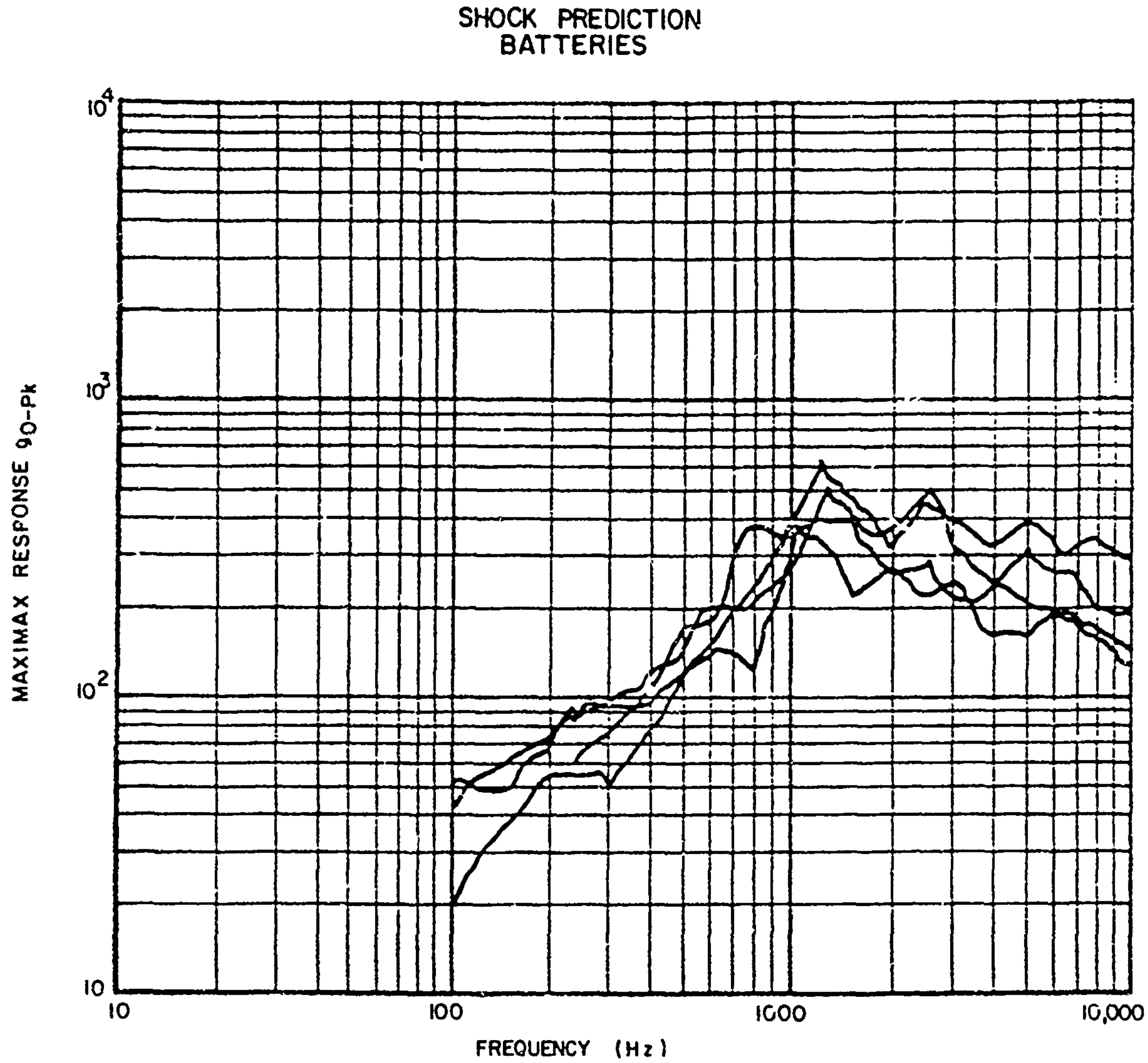
o—o— Ref. 1, Pg. 8
.——.— Ref. 2, Vol. III, Pg. 366
— —— Ref. 2, Vol. III, Pg. 419
.... Ref. 2, Vol. III, Pg 429
———— Ref. 2, Vol. III, Pg. 545

Referenced data are from tests of Marman clamps. Curves represent maximum spectra obtained 5 to 10 inches (127 to 254 mm) from the clamp for each of the six independent tests noted. It is predicted that the spectrum generated from the booster clamp ring acceleration will lie within the envelope of the above curves.

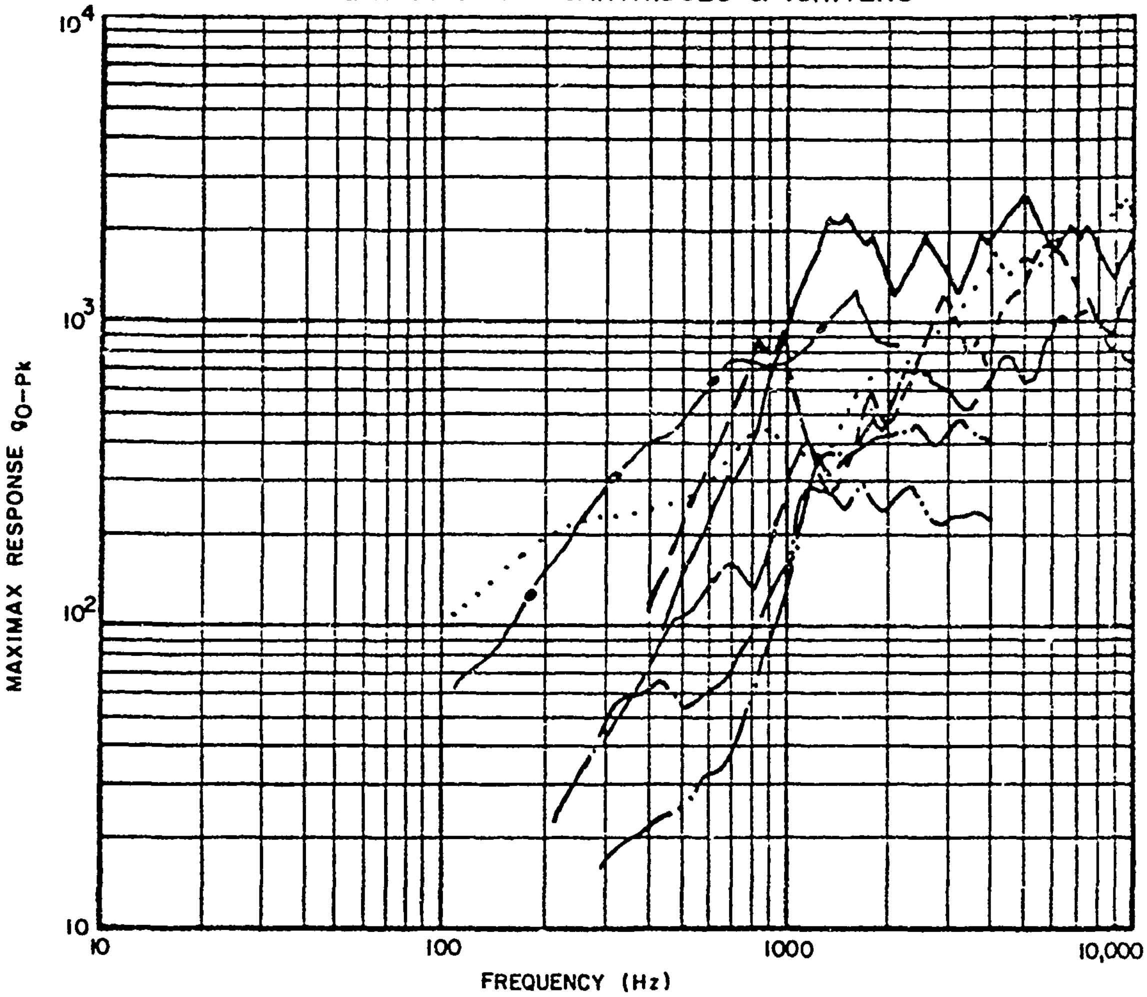
FIGURE 1



The above curves are plots of the spectra generated from transients of similar magnitude and frequency as the transient obtained from the initiation of the UpSTAGE battery as presented in Reference 5. The spectra shown were obtained from References 6 and 7. It is predicted that spectra generated from quick activated batteries will lie within the envelope of the above curves.

FIGURE 2

ENGINE START CARTRIDGES & IGNITERS



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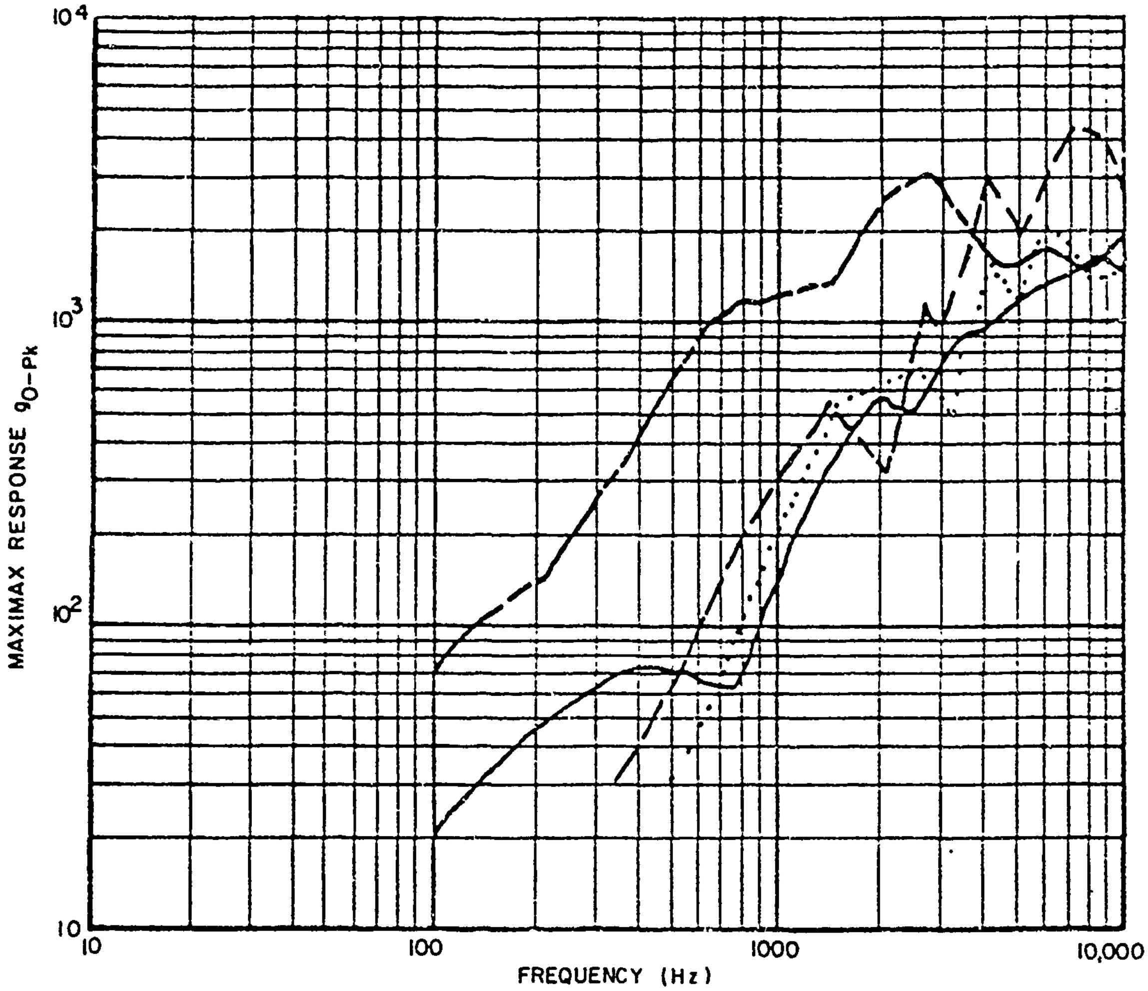
— — — Ref 4, Pp 8-58
·········· Ref 4, Pp 8-59
———— Ref 4, Pp 8-49
—o— Ref 4, Pp 7-19
—·— Ref 8
—··— Ref 8

Referenced data were obtained from Spartan and UpSTAGE tests. The Spartan test data were from transducers located 30 inches (762 mm) from the shock source and were modified to represent levels that could be expected within 5 to 10 inches (127 to 254 mm) from the source, as explained in Para. 2.3. It is predicted that spectra generated from accelerations caused by engine start cartridges and igniters will lie within the envelopes of the presented curves.

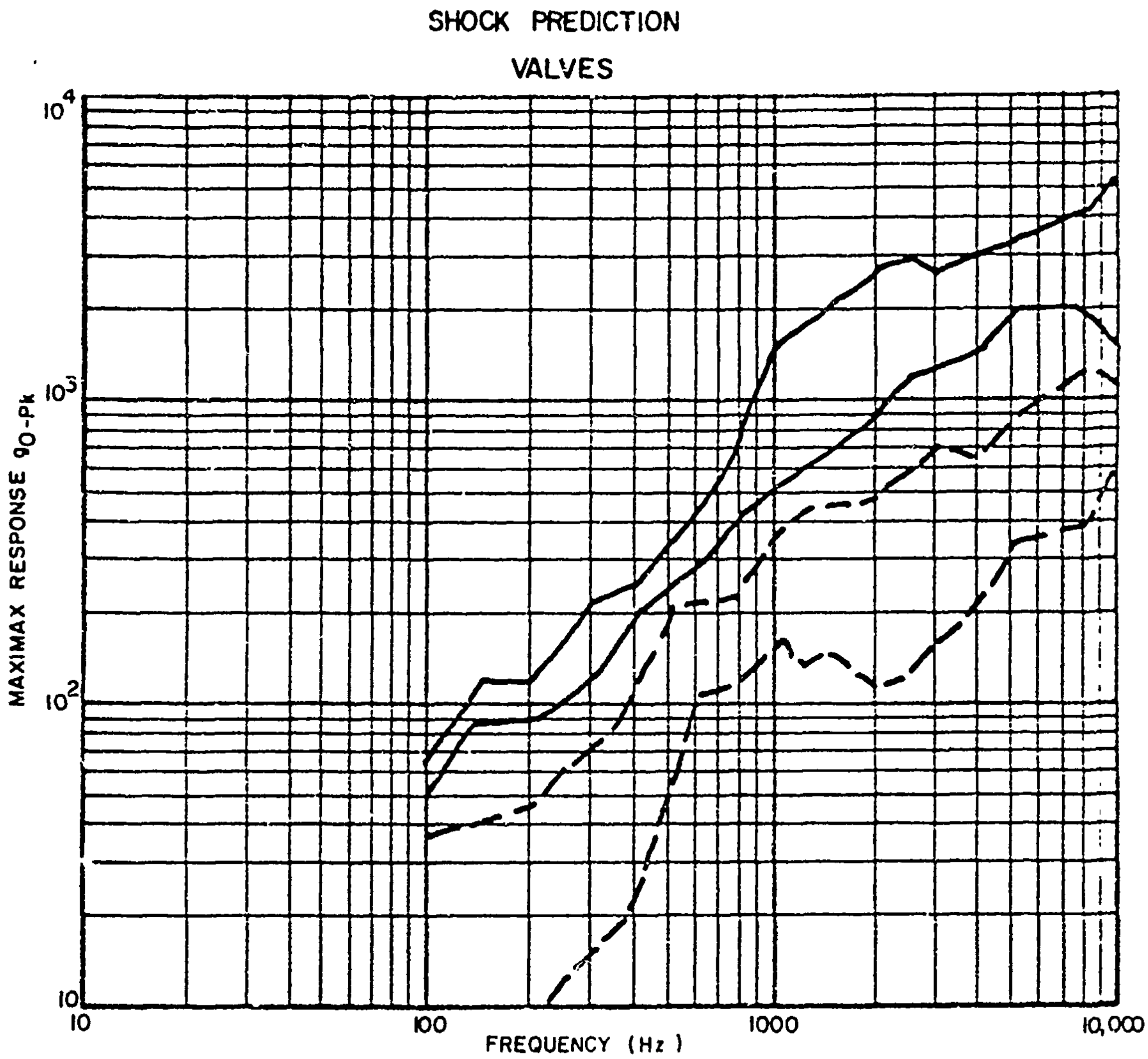
FIGURE 3

SHOCK PREDICTION
INLET COVER



———	Ref 2, Vol V, Pg 695 (Q=25)	Referenced data were obtained from four independent tests on pin pullers. It is predicted that the spectrum from the acceleration transient produced by releasing the inlet cover will lie within the envelope of the above curve.
– – – –	Ref 2, Vol V, Pg 709 (Q=25)	
——– –—–	Ref 2, Vol III, Pg 348 (Q=10)	
········	Ref 2, Vol III, Pg 605 (Q=20)	

FIGURE 4



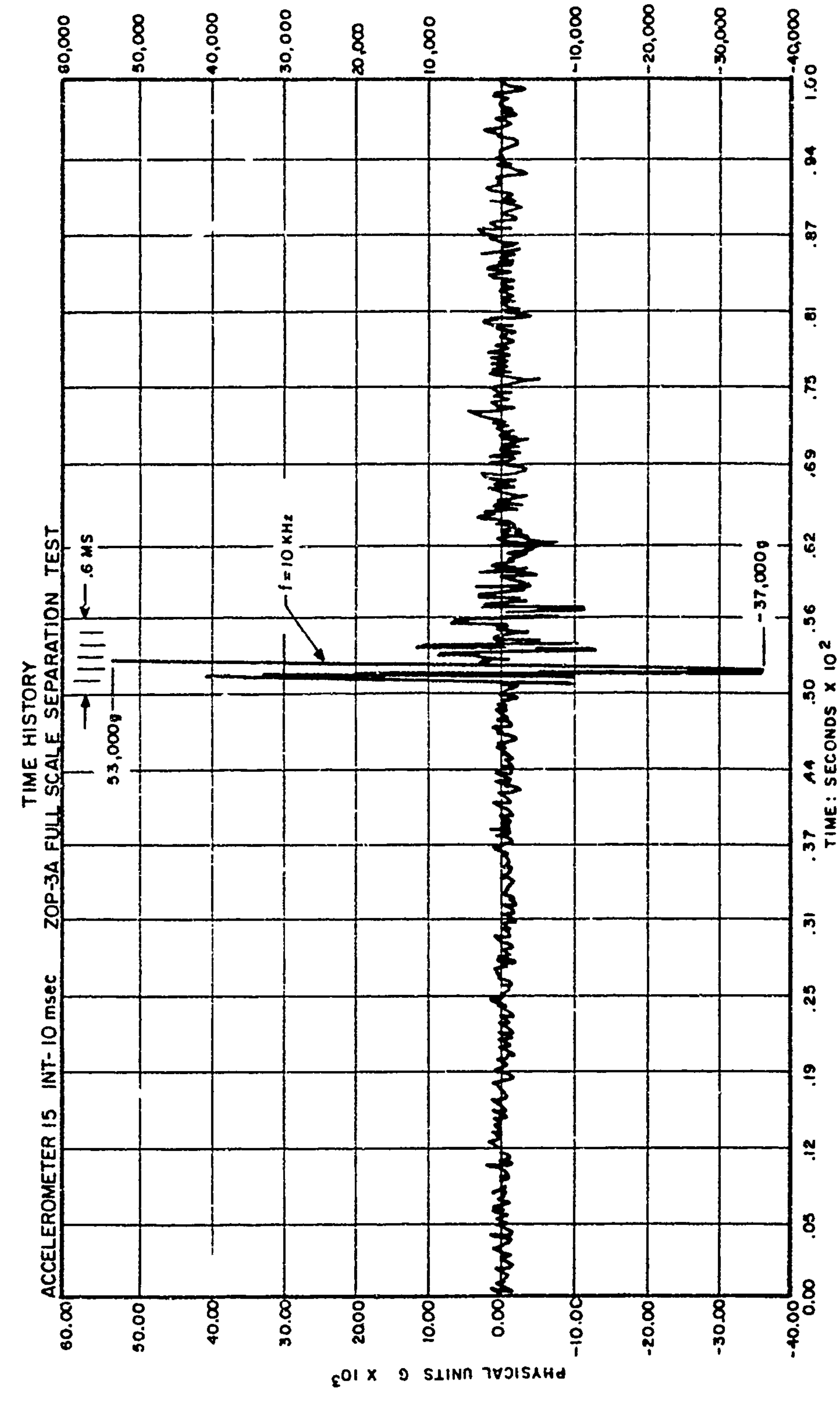
——— Valve Piston Axis Parallel to Mounting Surface

– – – – Valve Piston Axis Perpendicular to Mounting Surface

Envelopes reflect shock spectra obtained from tri-axial measurements taken 5 inches (127 mm) from the source. Five firings using identical 3/4-inch (19-mm) valves were made.

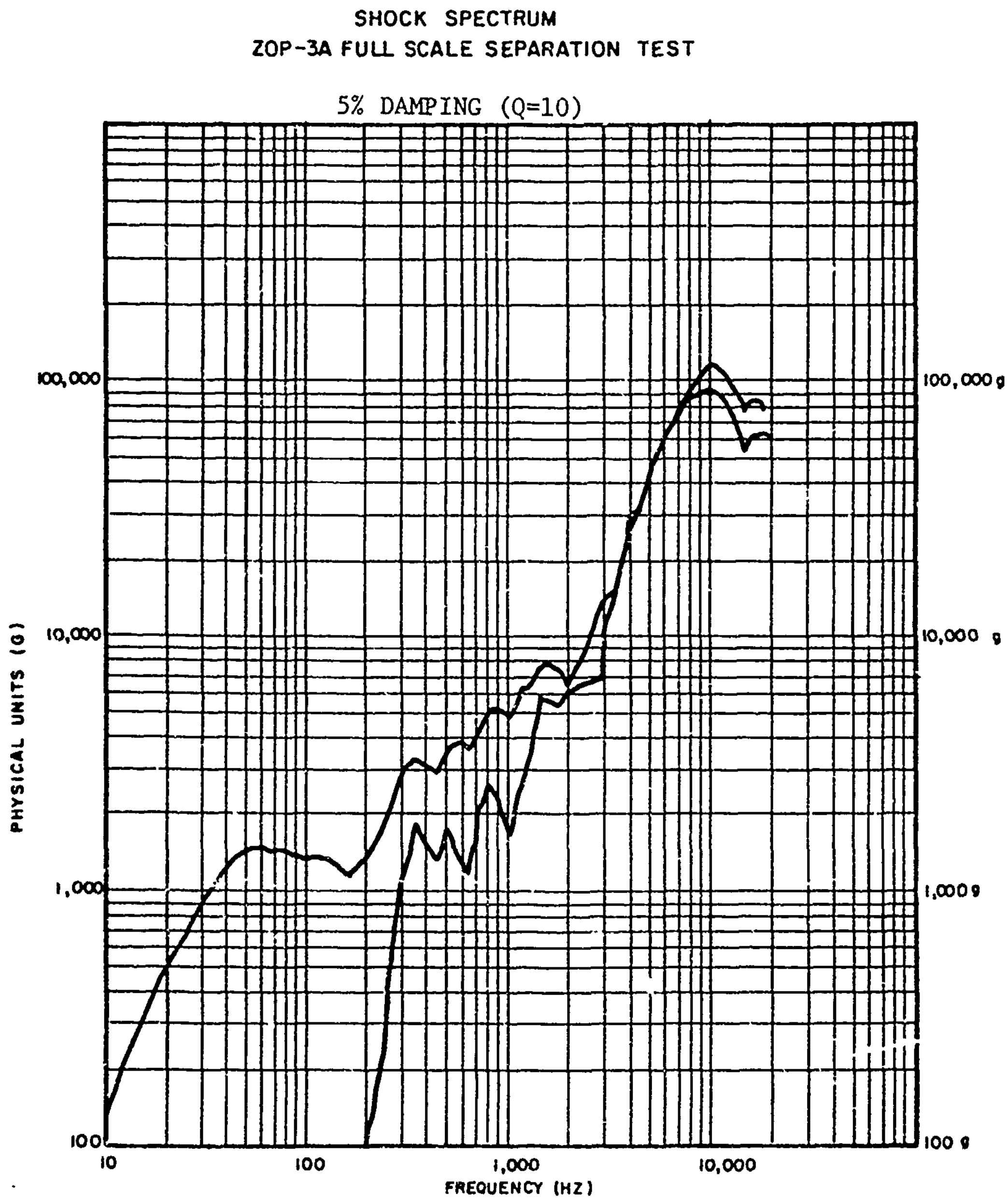
5% damping (Q=10)

FIGURE 5



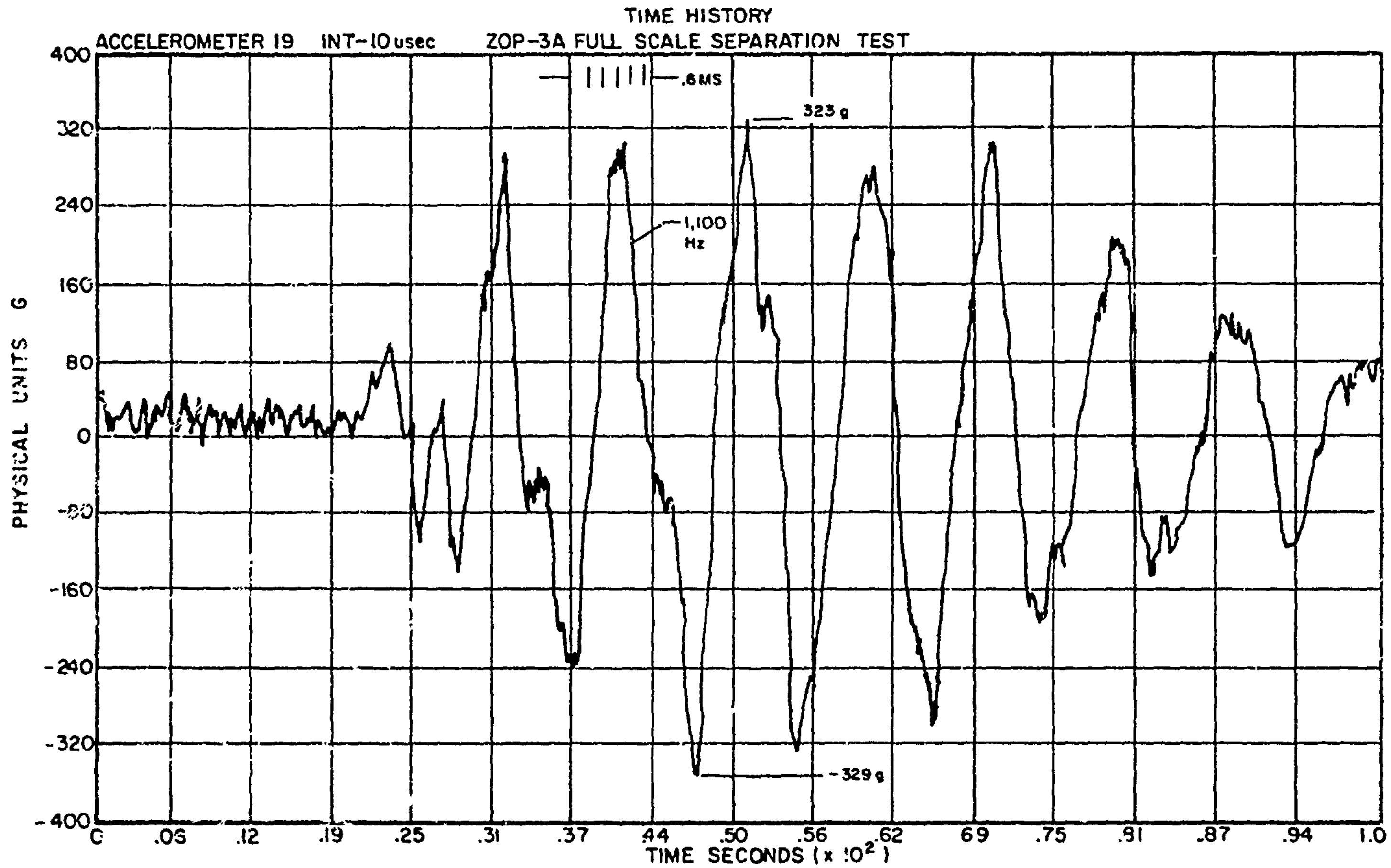
ACCELERATION HISTORY NEAR SEPARATION PLANE DURING STAGE SEPARATION

FIGURE 6



SHOCK SPECTRA NEAR SEPARATION PLANE DURING STAGE SEPARATION

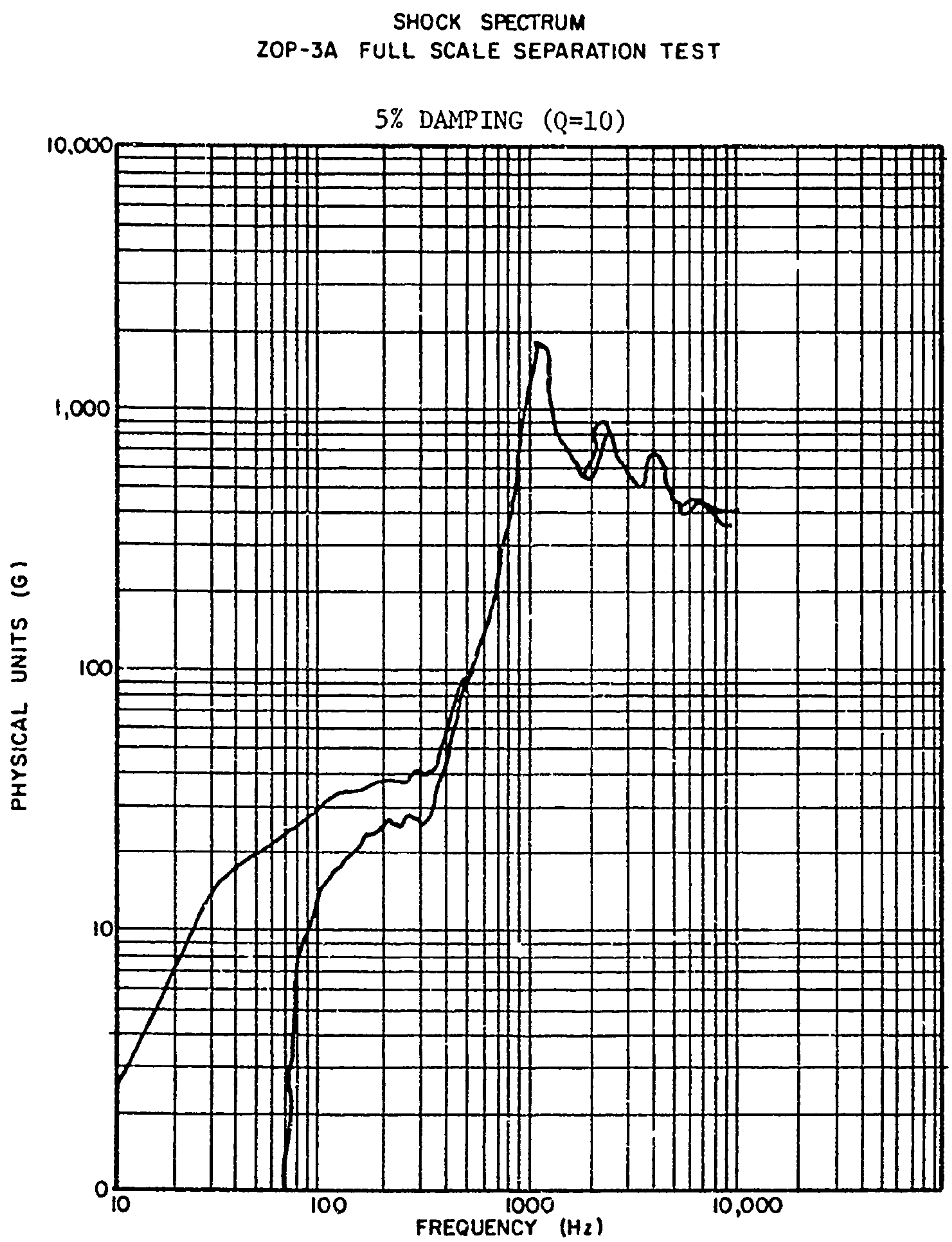
FIGURE 7



ACCELERATION HISTORY 175 IN. (4.4 m) FROM SEPARATION PLANE

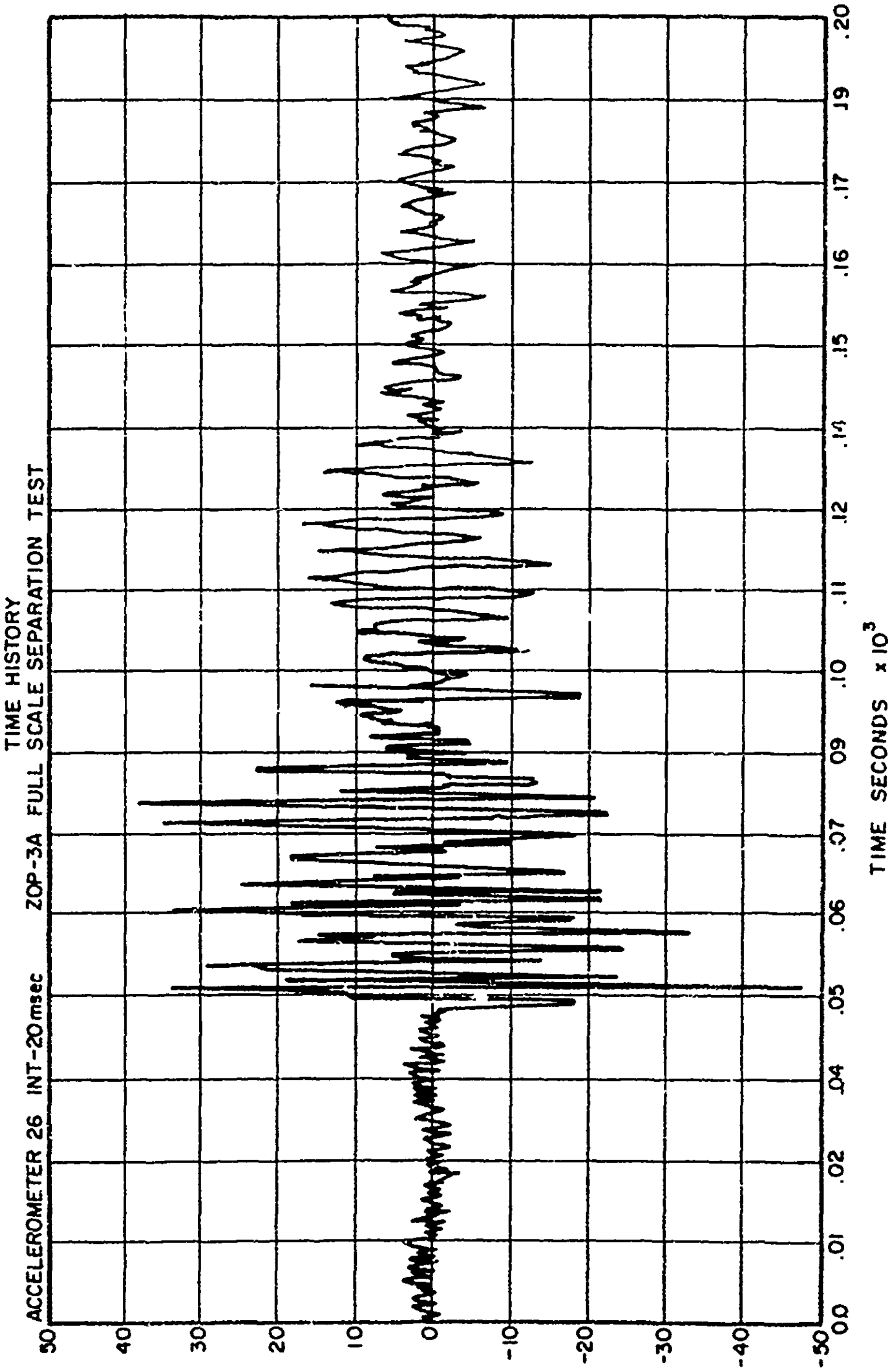
DURING STAGE SEPARATION

FIGURE 8



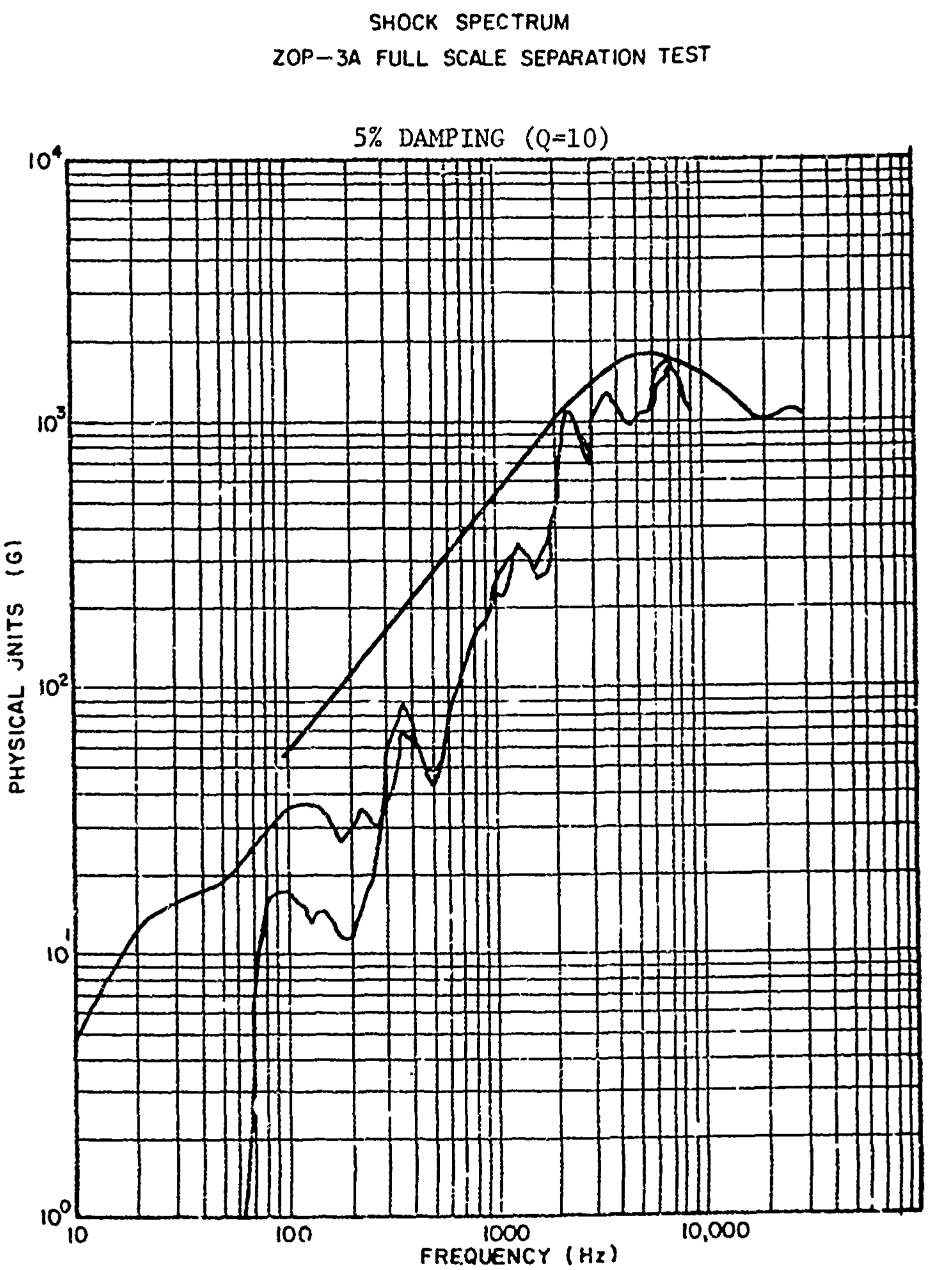
SHOCK SPECTRA 175 IN. (4.4 m) FROM SEPARATION PLANE DURING STAGE SEPARATION

FIGURE 9



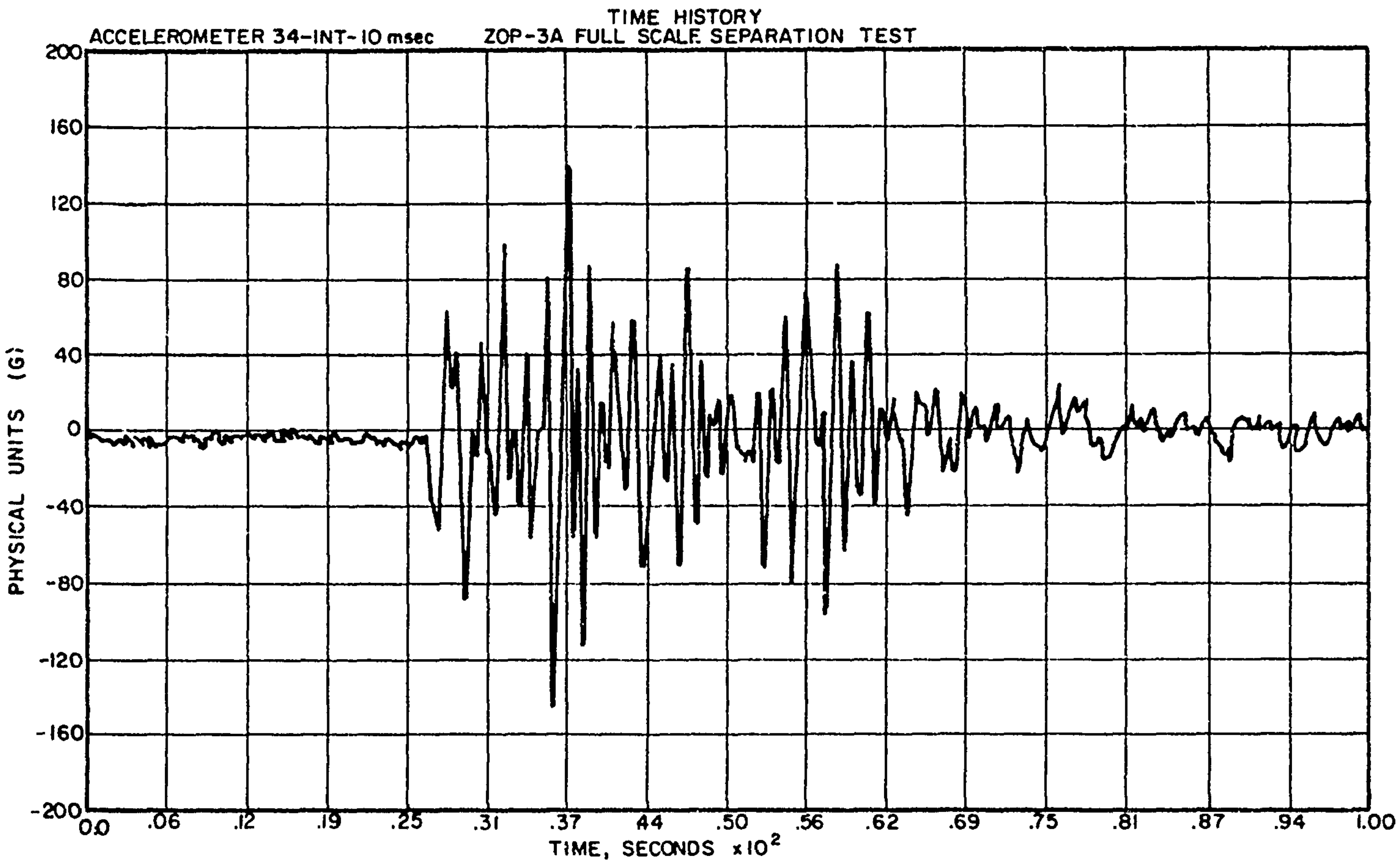
ACCELERATION HISTORY AT INTERMEDIATE LOCATION BETWEEN MISSILE JOINT AND MISSILE STATION 175

FIGURE 10



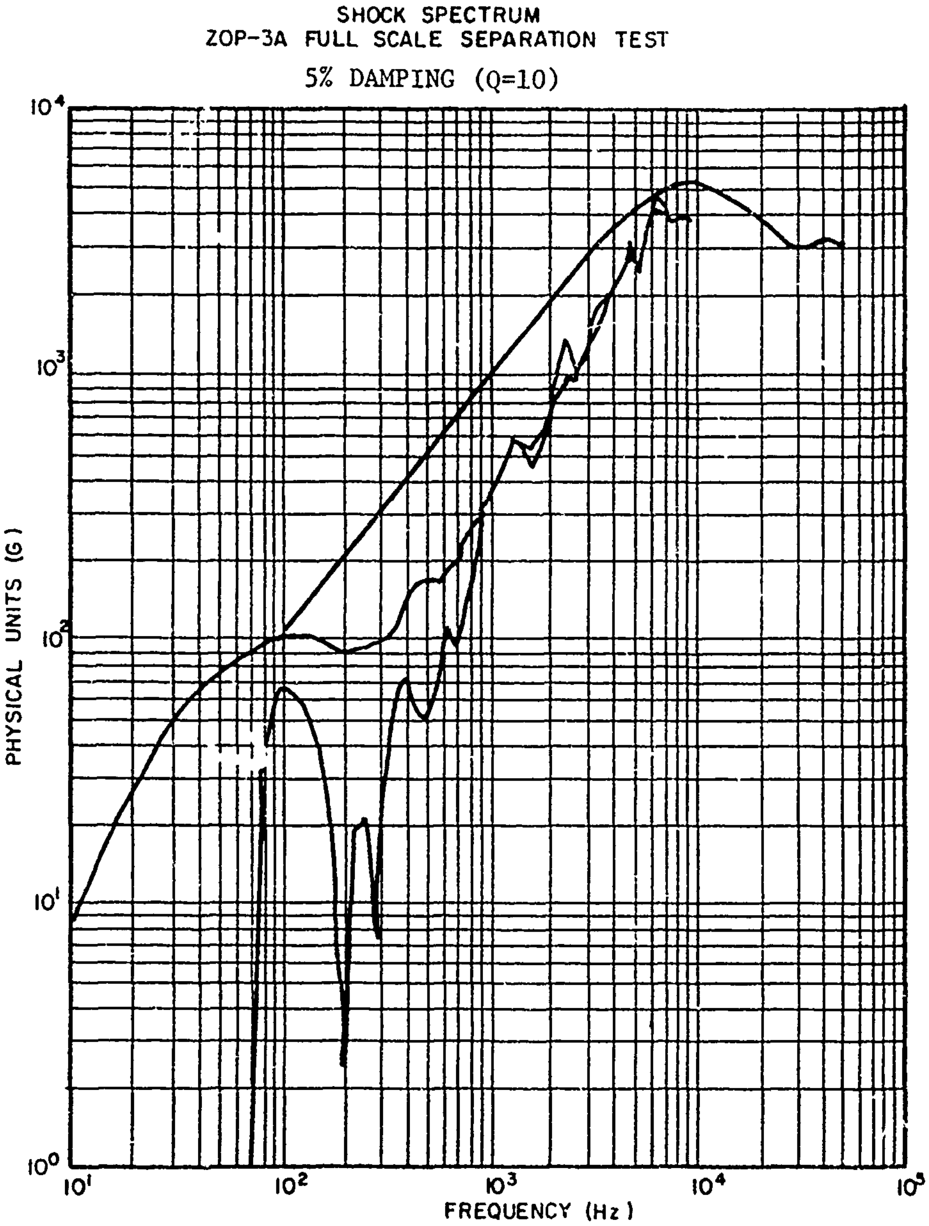
SHOCK SPECTRA AT INTERMEDIATE LOCATION BETWEEN MISSILE JOINT AND MISSILE STATION 175

FIGURE 11



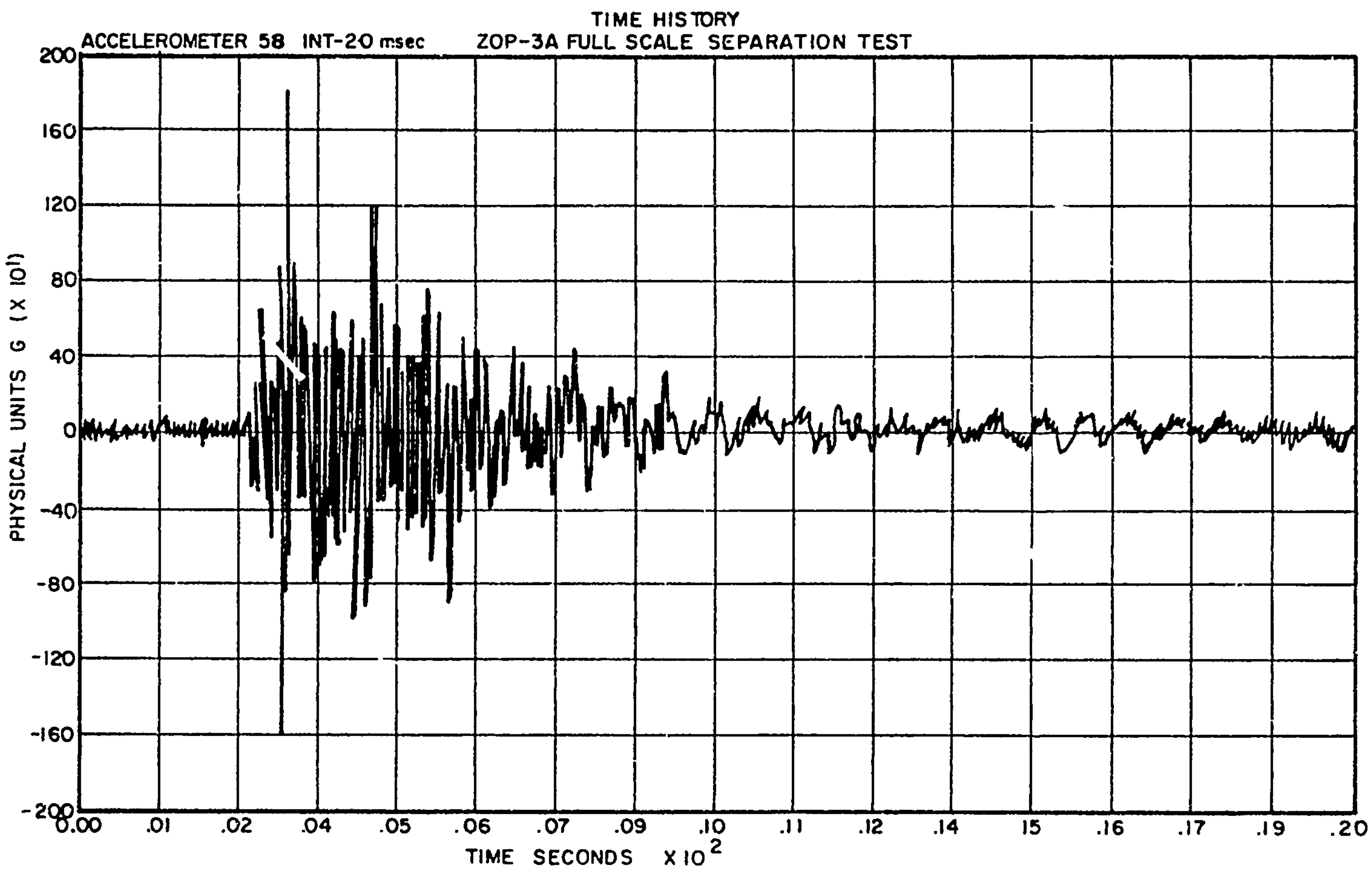
ACCELERATION HISTORY AT INTERMEDIATE LOCATION BETWEEN MISSILE JOINT AND MISSILE STATION 175

FIGURE 12



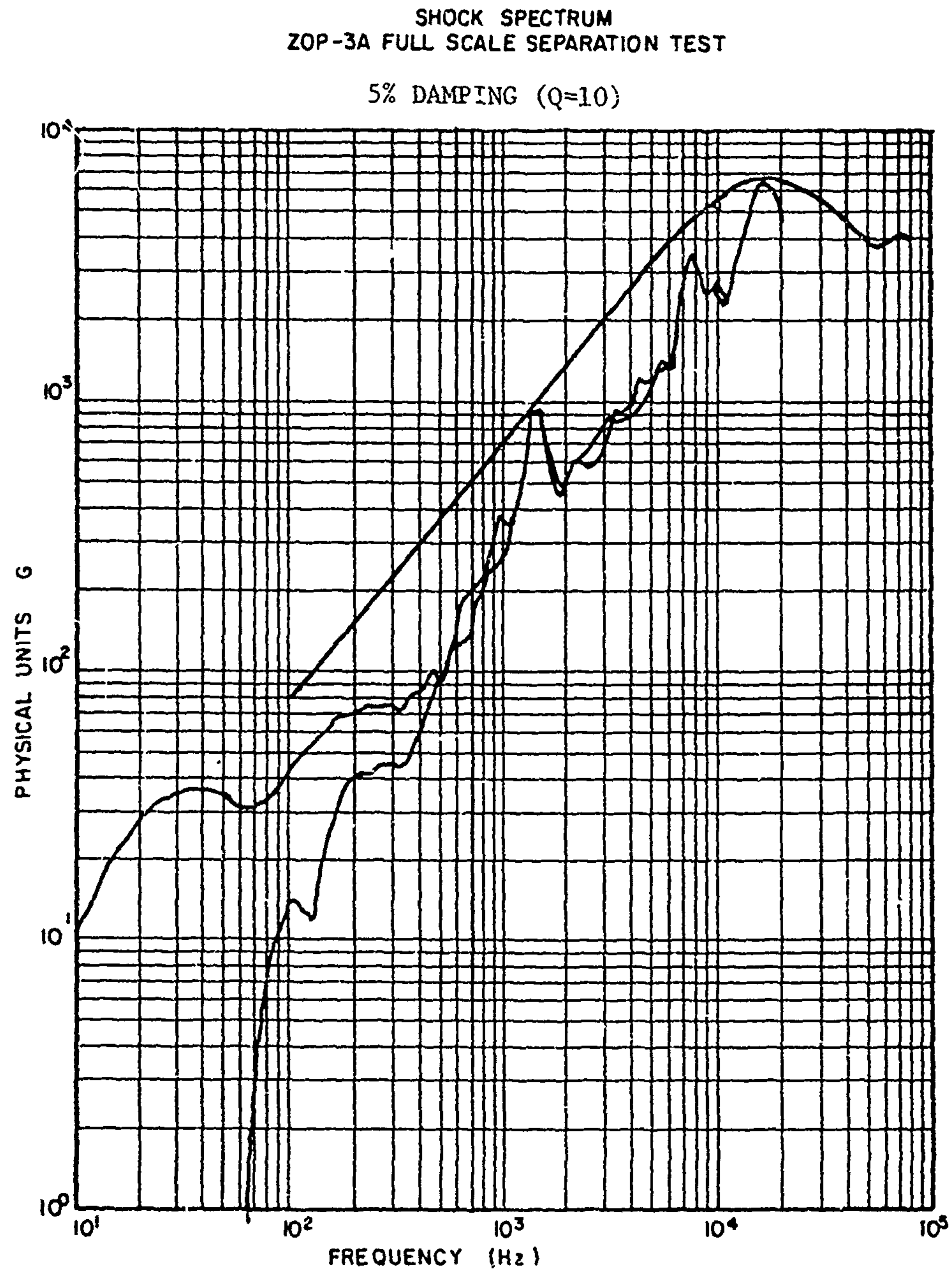
SHOCK SPECTRA AT INTERMEDIATE LOCATION BETWEEN MISSILE JOINT AND MISSILE STATION 175

FIGURE 13



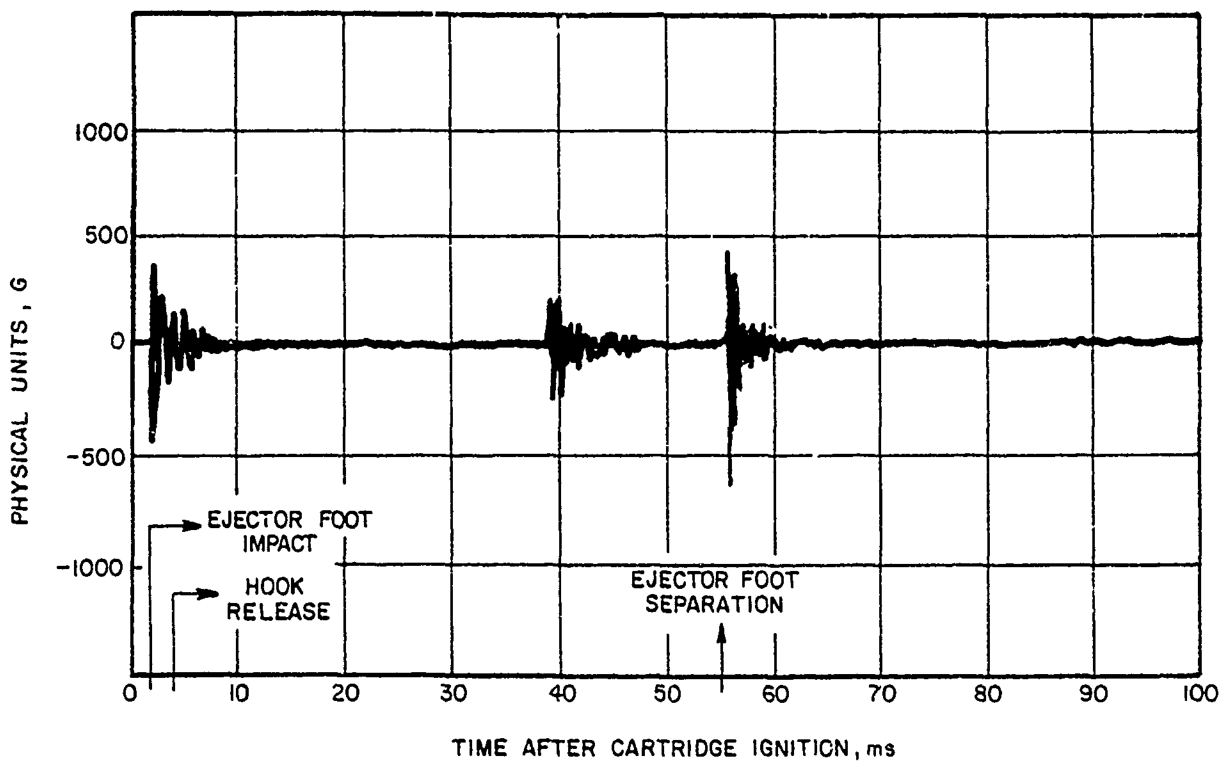
ACCELERATION HISTORY AT INTERMEDIATE LOCATION BETWEEN MISSILE JOINT AND MISSILE STATION 175

FIGURE 14



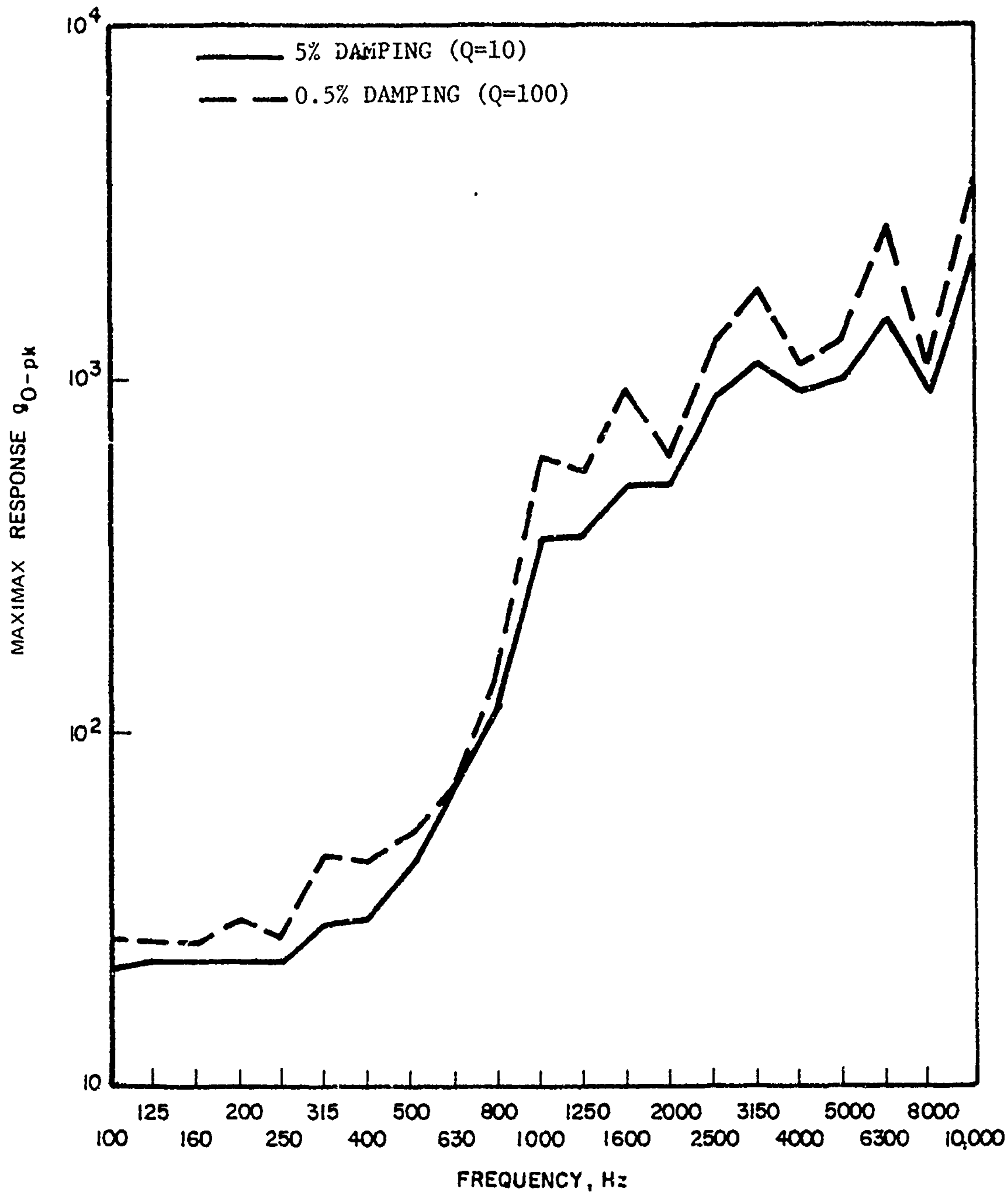
SHOCK SPECTRA AT INTERMEDIATE LOCATION BETWEEN MISSILE JOINT AND MISSILE STATION 175

FIGURE 15



ACCELERATION HISTORY AT EJECTOR FOOT LOCATION DURING MISSILE EJECTION TEST (AERO-7A-1 RACK WITH HIGH-FORCE CARTRIDGES).

FIGURE 16



MAXIMAX SHOCK SPECTRA FOR 5% DAMPING (Q=10) and 0.5% DAMPING (Q=100)
AT EJECTOR FOOT LOCATION DURING MISSILE EJECTION TEST
(AERO-7A-1 RACK WITH HIGH-FORCE CARTRIDGES).

FIGURE 17

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